Evaluation of Active and Passive Gas Imagers for Transmission Pipeline Remote Leak Detection

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Detecting transmission pipeline leaks is important

Problem:

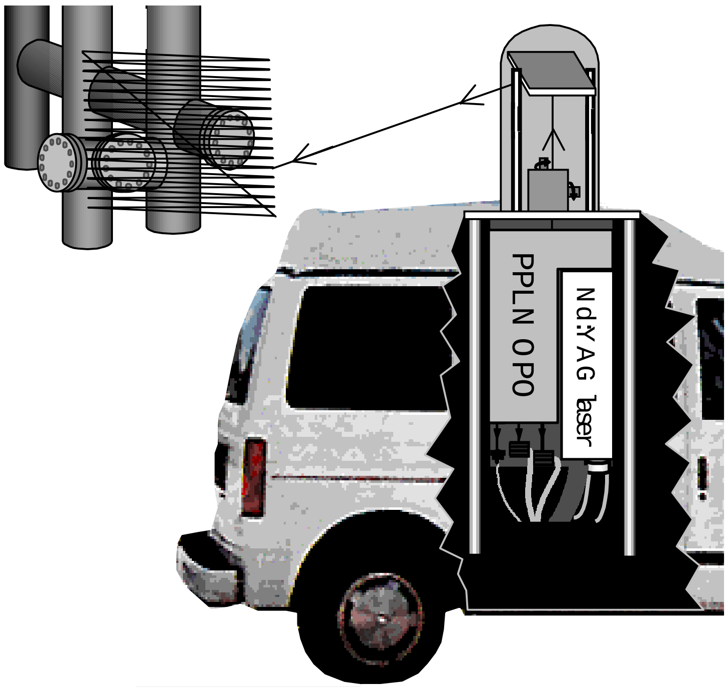
- Low-flying aircraft are sometimes used to discern discolored vegetation caused by gas leaks.
  - ➔ *Lack of vegetation in remote areas (e.g., the desert)*
- Ground-based air-sampling technique requires time

Need: Rapid method for transmission pipeline leak detection at low levels

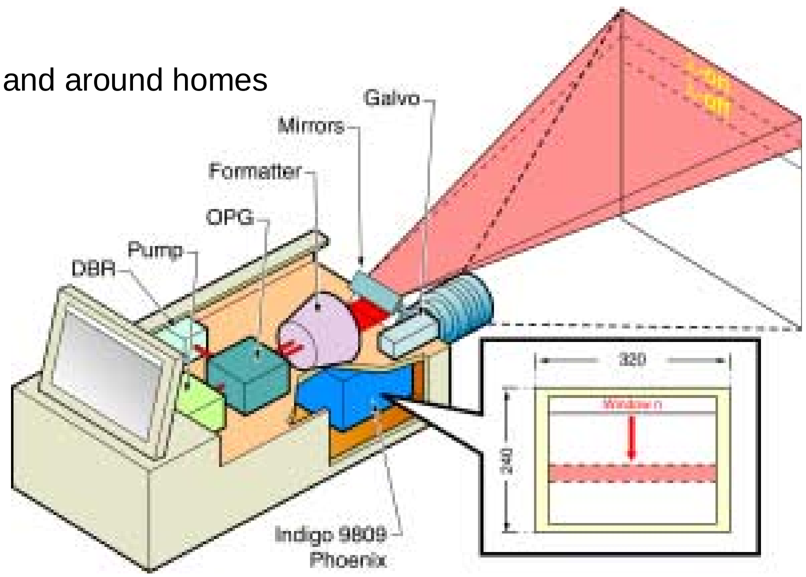
Potential solution: Optically-based stand-off-detection technologies have been developed to find gas leaks.

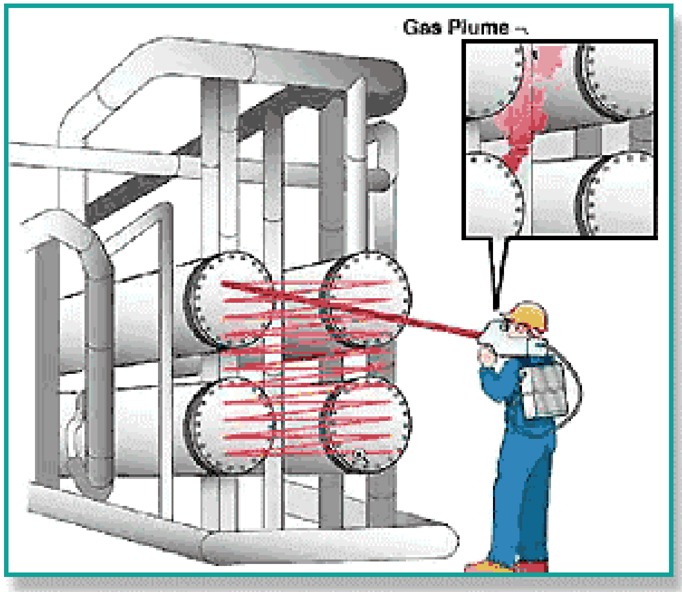
Technology has been demonstrated for shorter distances

Vehicle-mounted imager
(refineries, gas distribution)



In and around homes

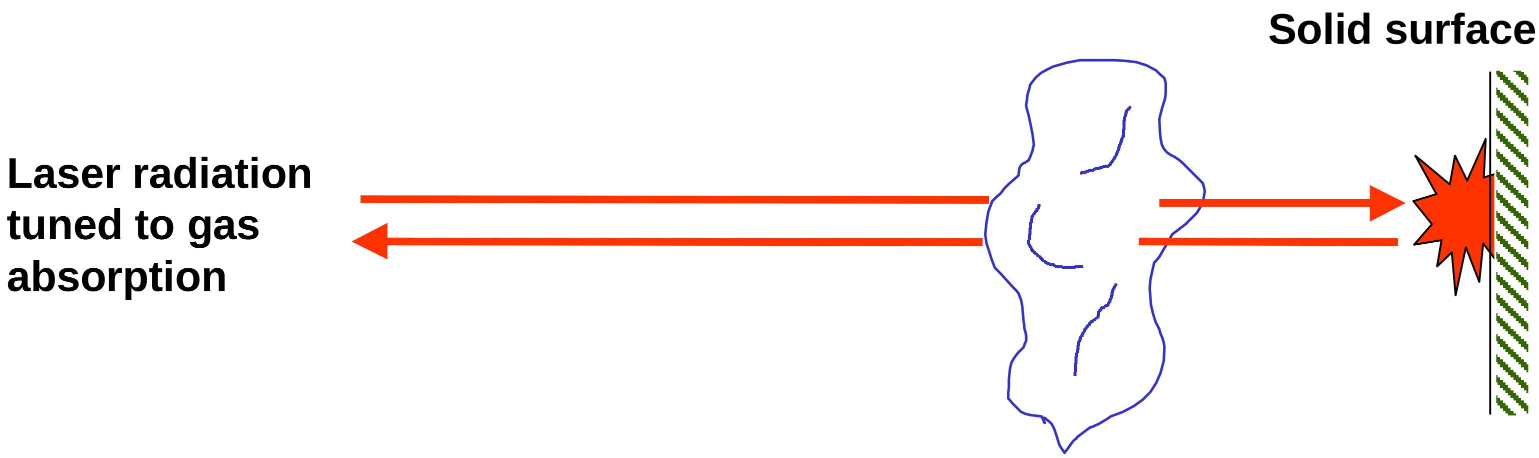


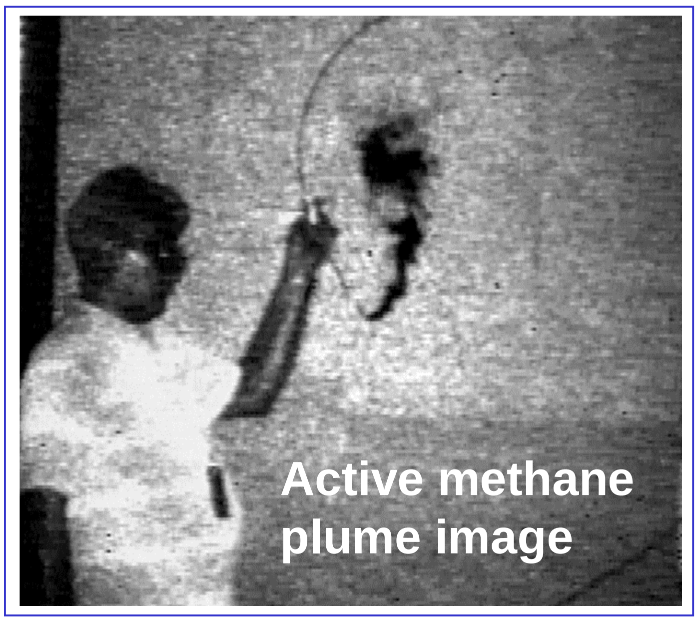


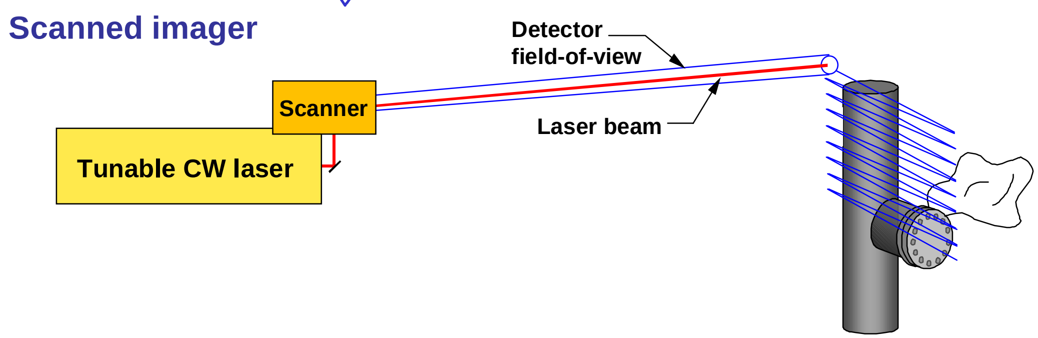
Refineries, compressor stations

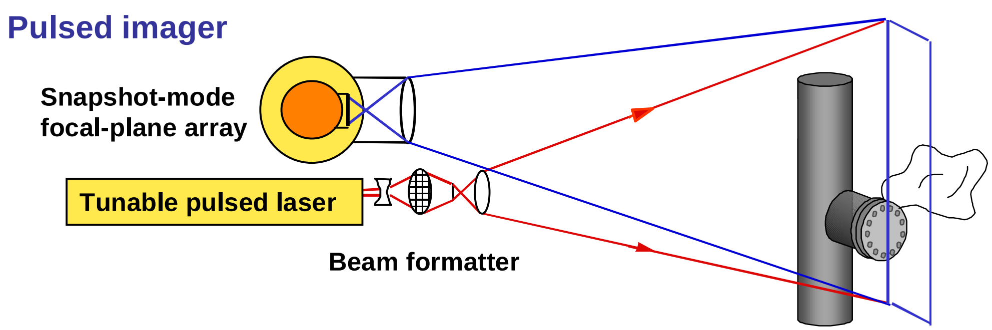
Technology seems adaptable to further remote applications.

Remote imaging or mapping simplifies plume detection

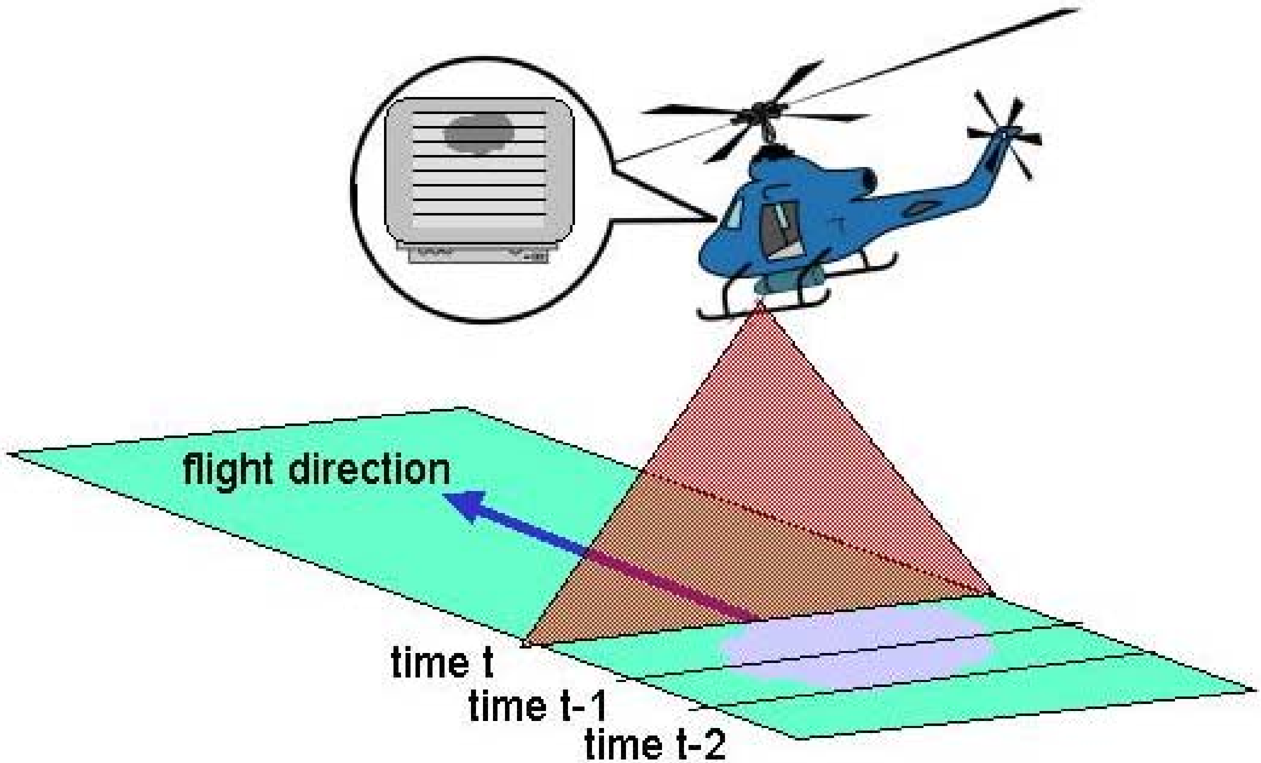




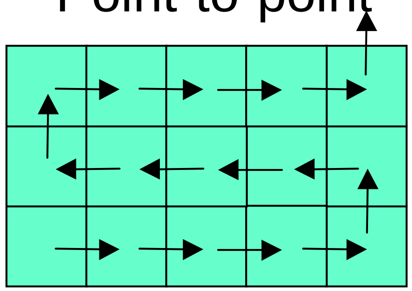




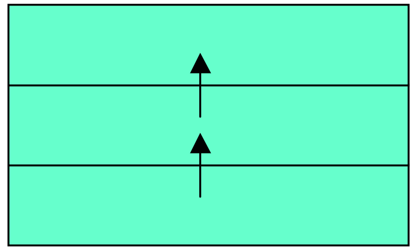
Proposed airborne detection scenario



Point-to-point



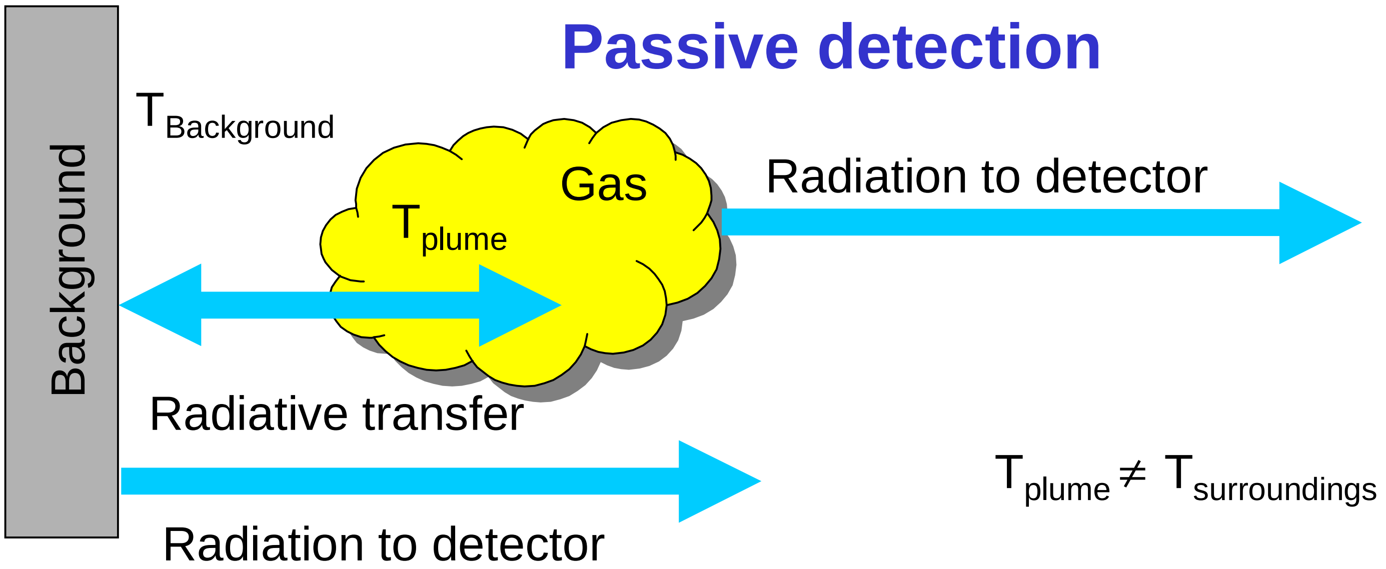
Push-broom



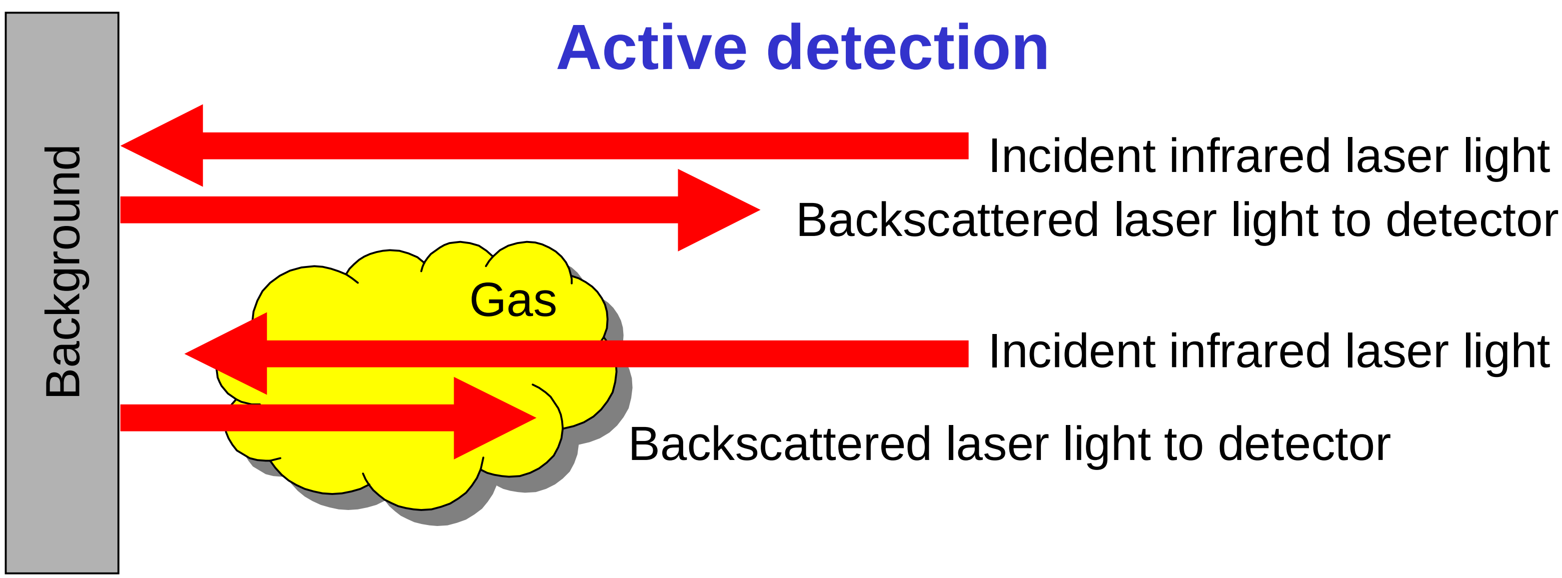
- Aircrafts fly at ~200 m for visual detection of discolored vegetation
- Typical flying speed is 120 mph (54 m/s)
- We will probe a 10-m side-to-side area at a 0.5-m resolution

Potential methods of remote detection

Passive detection



Active detection

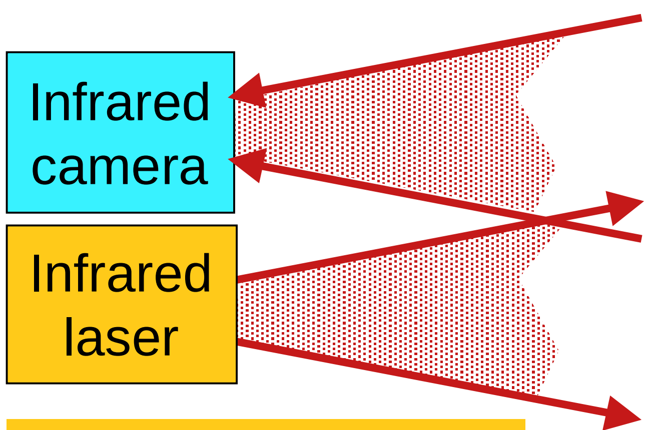


Compare performance of active and passive detection

Passive detection

Transmits at gas absorption wavelength

Active detection



Tuned to gas absorption wavelength

	Advantages	Disadvantages
Passive detection	No laser required No background needed Very long range Multi-λ information	Requires ΔT Signal may be low
Active detection	No ΔT needed Signal high	Requires laser Needs background Signal $\rightarrow$(range)$^{-2}$ Generally only a few λ's

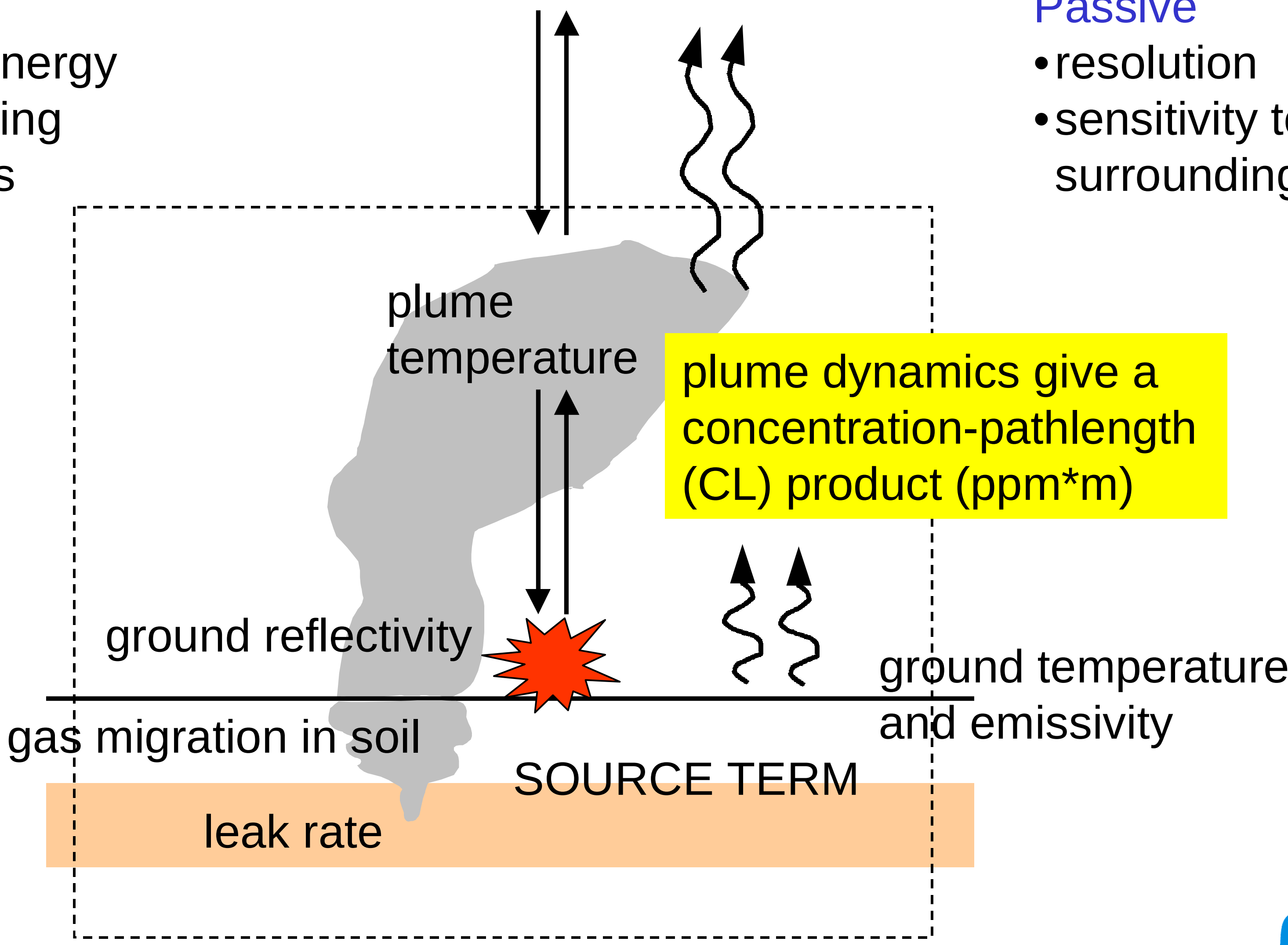
Efforts to detect leaks in transmission pipelines remotely

- Ophir Corporation (Littleton, CO): Gas correlation radiometry with spectrally broad illumination source
- LaSen, Inc. (Las Cruces, NM): Pulsed active imager
- Gasoptics (Lund, Sweden): Gas correlation radiometry with thermal radiation
- Boreal Laser (Spruce Grove, AB., Canada): Aircraft-mounted point sensor to sample the air above a leak

There are many technical issues involved in this evaluation

Active
- laser energy
- scattering physics

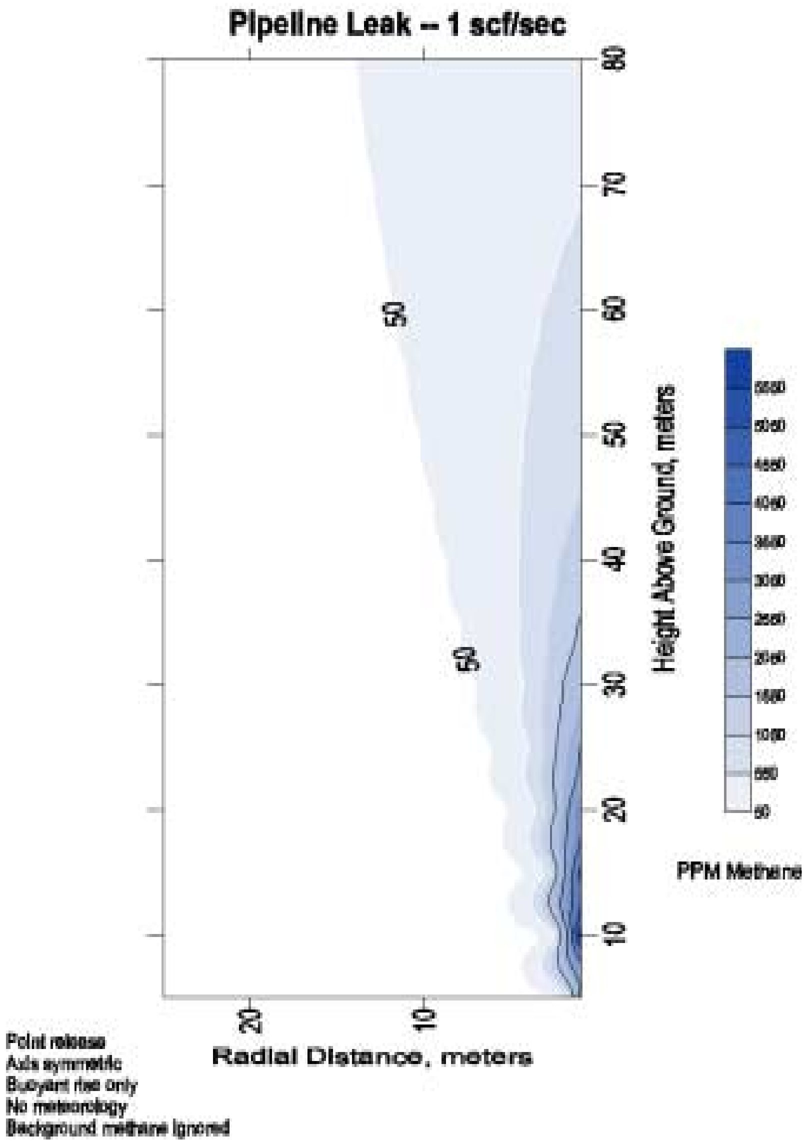
Passive
- resolution
- sensitivity to surroundings



Technical tasks

- Model plume behavior to calculate required detection limits
- Do we have the ability to go the distance?
  - ➔ Compare active and passive detection
  - ➔ Perform both experiments and calculations
- Examine *all* noise sources and *all* interferences (background radiation, detector and amplifier electronic noise, ambient methane absorption)
- Propose airborne detection scheme

Model plume to calculate required detection limits



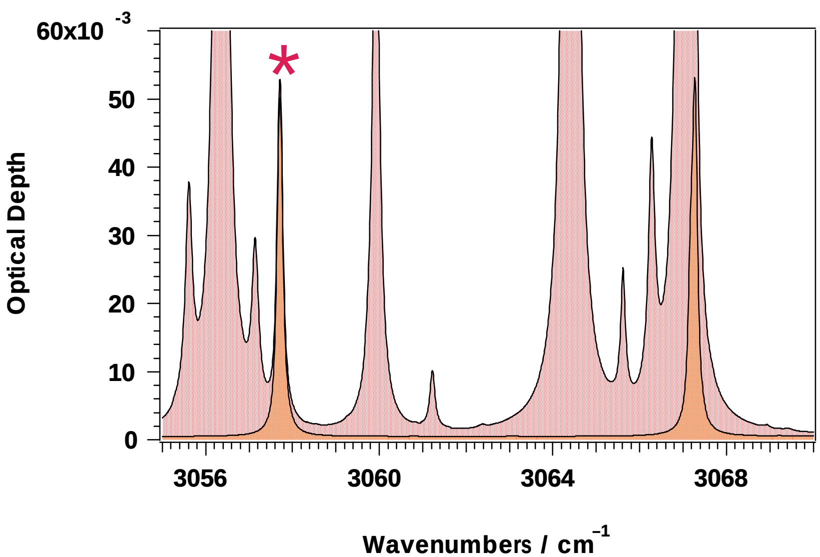
- Large array of parameters

- Bracket leak conditions:
  - a) 2 leak sizes: 0.003 in^2 @ 400 psi and 0.010 in^2 @ 1000 psi
  - b) 2 soil effects: compact (clay) and loose (sand)
  - c) 2 wind speeds: 1 m/s and 10 m/s
  - d) 3 atmospheric conditions: highly unstable, neutral, and highly stable

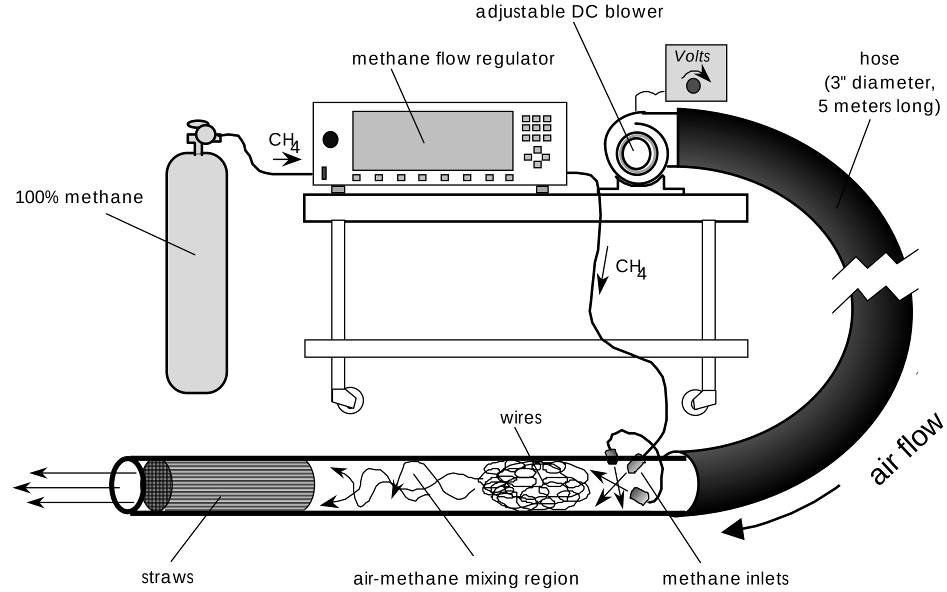
- Compute column-integrated methane (ppm-m)

- Results compared to predicted performance

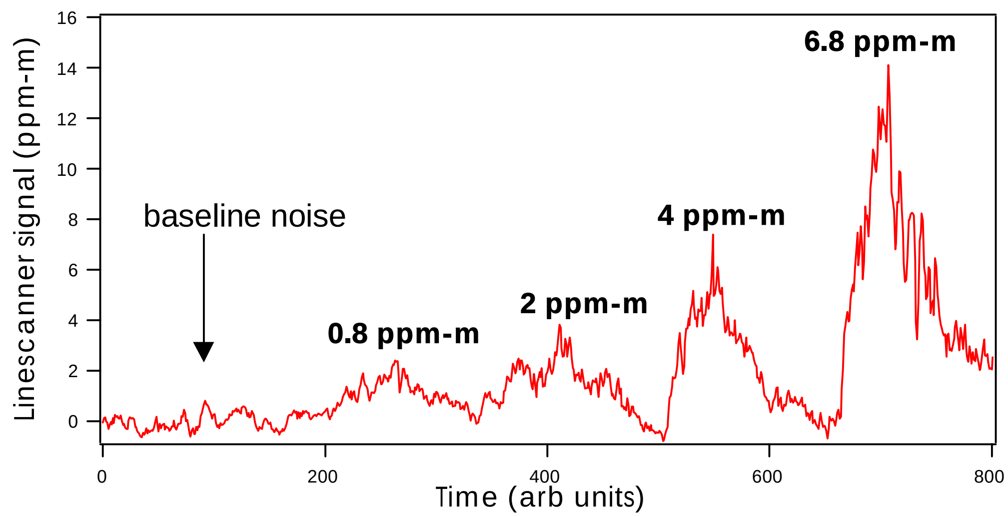
Detection limits using breadboard active system



Methane 10 ppm-m
Water 0.038 atm

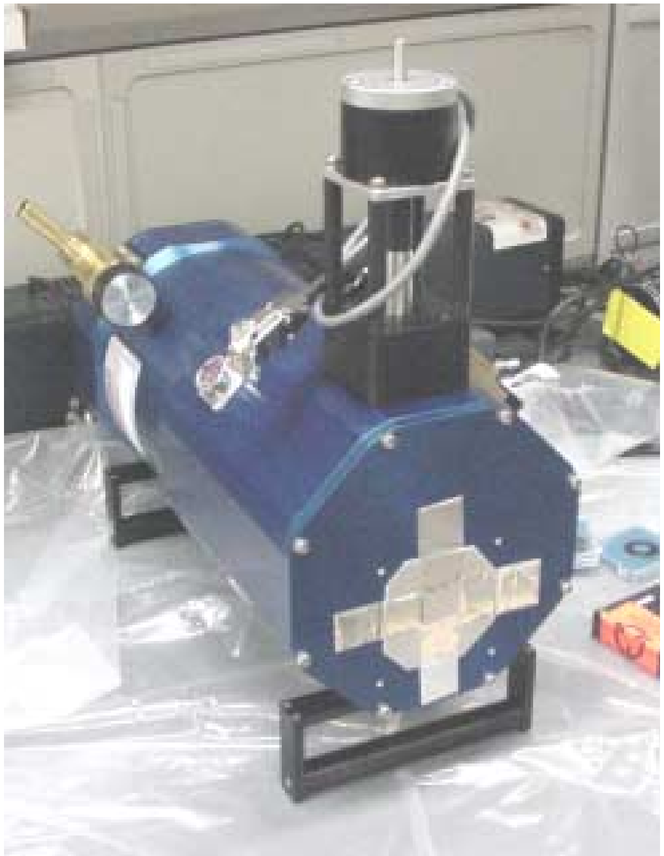


- Single shot detection limit = 8 ppm-m
- 100-pt average detection limit = 0.8 ppm-m
- Averaging samples decreases noise by $1/n^{1/2}$

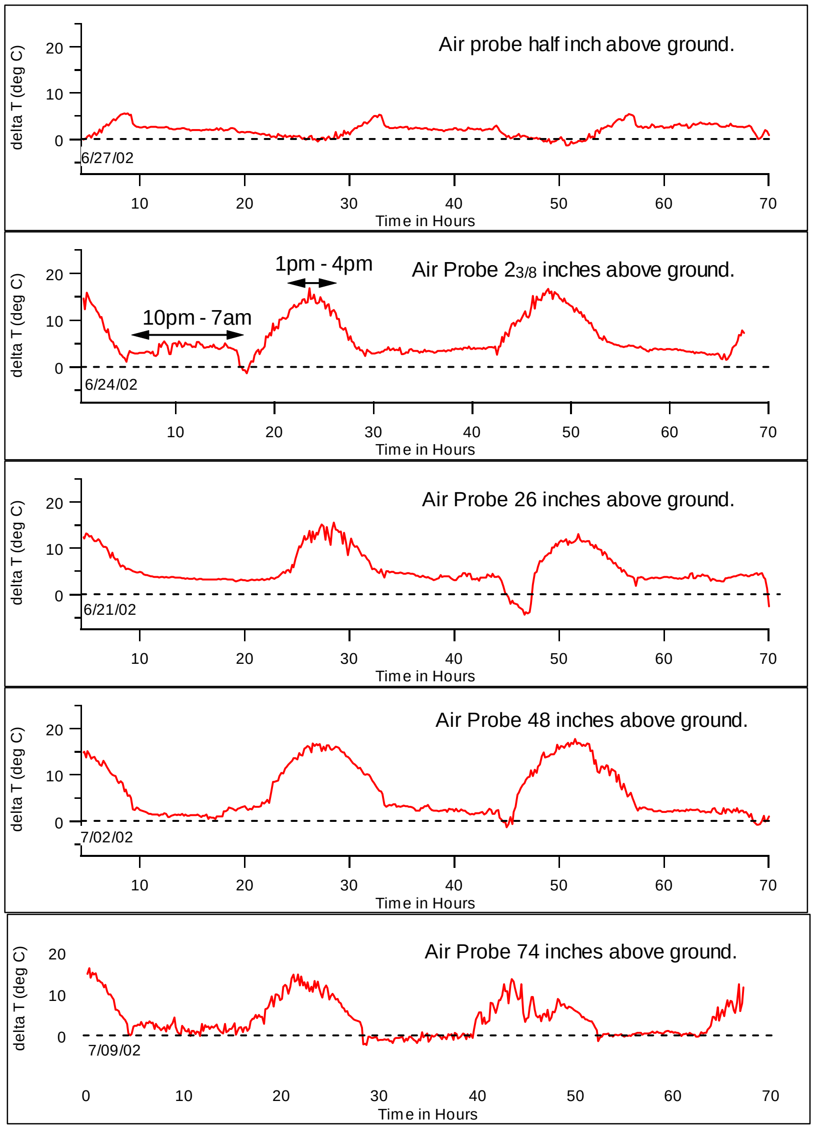


Detection limits using breadboard passive system

- Detection system uses available focal plane array, but requires a filtered dewar
- Dewar is being manufactured by IR Laboratories
- Filters procured for differential detection of butane
- Also performing methane studies with Midac passive FTIR



Passive system detection limit depends on time of day



Sunny weather

Sunny weather

Mixed conditions

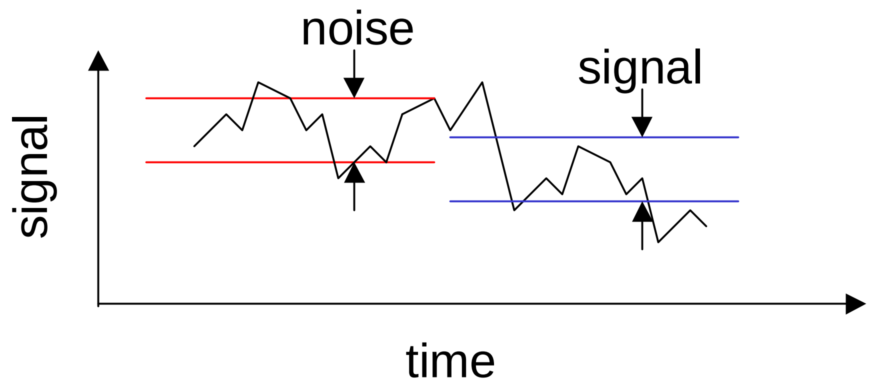
Sunny weather

Cloudy weather

- Passive system detection limit depends on the temperature difference
- Temperature difference varies considerably throughout the day
- Typical temperature difference is ~5ºC.

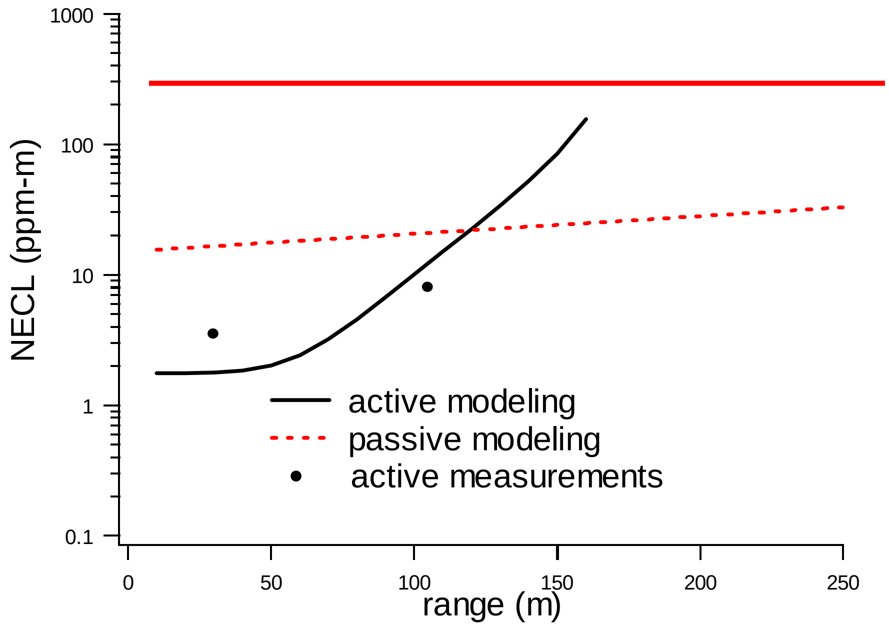
Quantify merits of active and passive detection

- Evaluate the *NECL* (noise-equivalent concentration-length product), the concentration-length product that results in a signal strength equivalent to the noise



- The lower the NECL, the better (detection limit is 3-5 times the NECL)

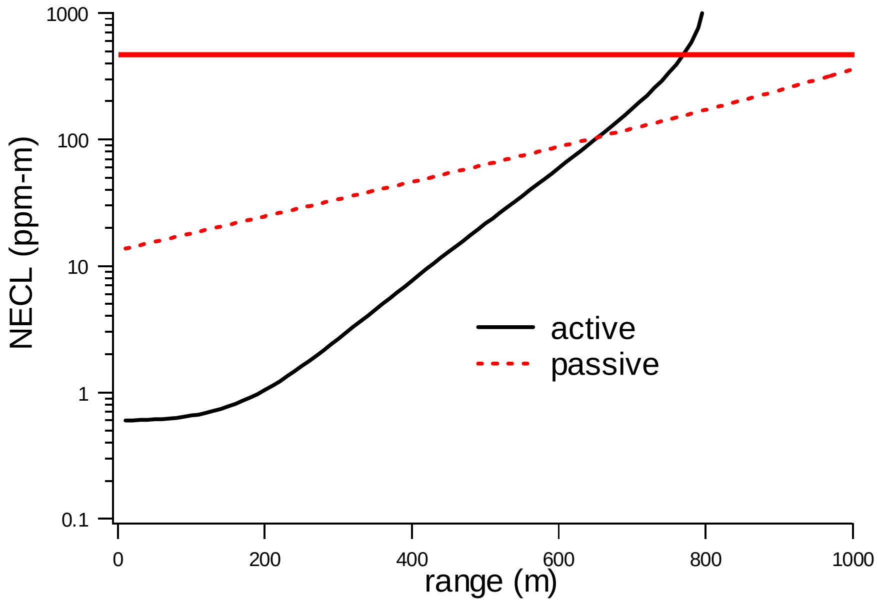
Analysis of current breadboard systems

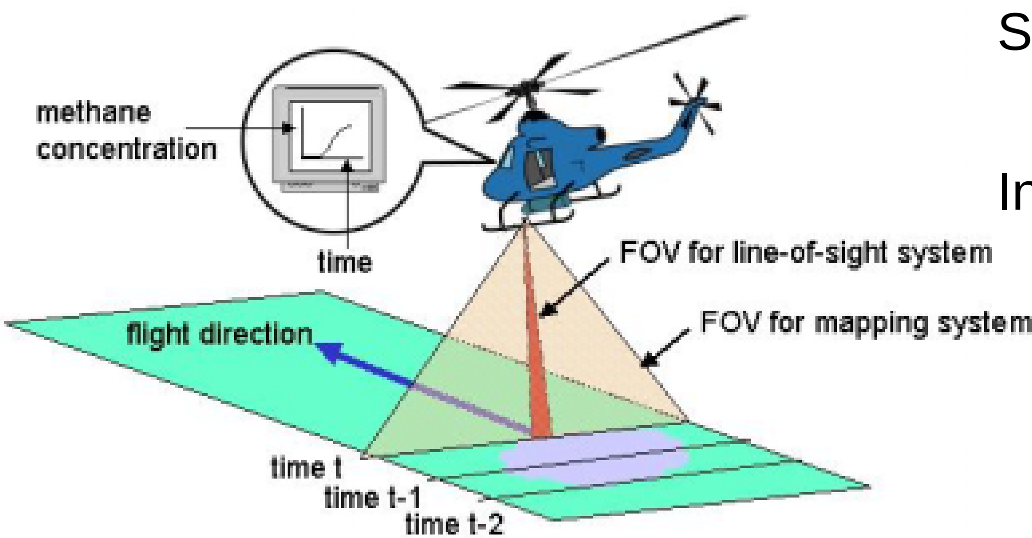


- Active system is limited by laser energy and pre-amp performance at long distances
- Passive system NECL is not a strong function of range

Leak	Atmosphere	Wind speed	Soil	ppm-m
0.010 in^2 @ 1000 psi	very unstable	10 m/s	compact	541
0.003 in^2 @ 400 psi	neutral	10 m/s	compact	281
0.003 in^2 @ 400 psi	neutral	10 m/s	loose	47
0.003 in^2 @ 400 psi	very stable	1 m/s	compact	5840

Analysis of systems designed for airborne deployment





System improvements

- Increased laser repetition rate for active system (averaging)
- Tuned laser to Q-branch of methane
- Decreased spectral width of passive system (dispersive filtering scheme)

Systems would be designed for a single line-of-sight.

Instrument components: ~$120 K

Prescribe and build remote gas detection system for transmission pipelines

Active and passive systems with requisite performance have been designed

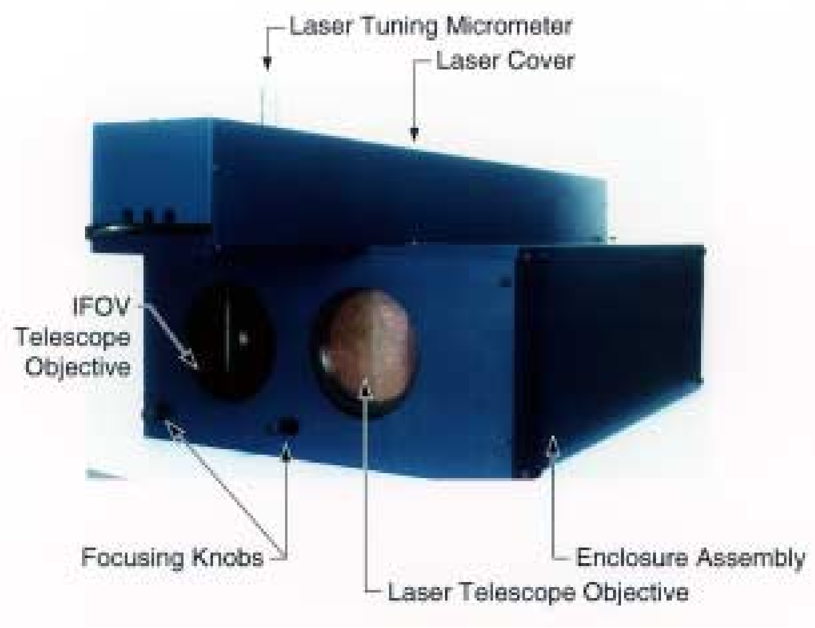
Choice between two designs waiting on final passive measurements

~1 year: Performance requirements for long-range airborne testing will be demonstrated

~2 years: System will be ruggedized sufficiently for airborne deployment and an airborne test will be performed

- Side cargo doors can be removed
- Bottom viewing port
- 3-wk field test with 20 hrs of flight time: $25K for aircraft use

Examples of gas-imaging systems engineered at Sandia



Rough specs for airborne system:

Size: 0.5 m^3

Weight: 40 kg

Power consumption: 500 W